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Photo 1. Researcher placing the portable GPS recorder.

Lingering Mysteries of the 1964 Earthquake

By Dr. Jeffrey T. Freymueller

Early in the evening of March 27, 1964 (5:36 p.m. local time), the ground began to shake across all of southern Alaska. The 1964 Great Alaska Earthquake, magnitude 9.2, was the second largest earthquake ever recorded within the roughly 100 years of the instrumental record, topped only by the 1960 (magnitude 9.5) Chile earthquake. During the five minutes of the earthquake, about 500 miles (800 km) of the Pacific tectonic plate slipped as much as 70-100 feet (20-30 m) beneath North America. Buildings and oil tanks collapsed; roads, railroads, and bridges were destroyed; and the collapse of several segments of seaside bluffs destroyed numerous homes and businesses in Anchorage. In Seward, now the administrative home of Kenai Fjords National Park, the worst was soon to come. A deadly tsunami, or seismic sea wave, was triggered by the sudden uplift of the seafloor, and it destroyed the waterfront as it surged into Seward and other coastal communities. The tsunami also propagated across the Pacific Ocean, causing deaths in Hawaii and California. A total of 131 people died, 115 in Alaska.

Earthquakes are a sudden slippage of rocks past each other on a fault, or break in the earth. The 1964 earthquake occurred on a fault that separates the Pacific tectonic plate from the North American plate *(Figure 1)*. The Pacific plate moves north-northwest at a rate of about 2.2 inches (5.6 cm) per year relative to North America. At the southern coast of Alaska, the Pacific plate pushes beneath North America, thrusting down to the north at an angle of only a few degrees, before eventually diving down deep into the earth. Large earthquakes occur on this fault because the two sides of the shallow part of the fault are usually locked together by friction, which keeps them from slipping past each other. But the Pacific plate never stops moving, and eventually enough force builds up to break the frictional contact. When this happens, in seconds to minutes the Pacific plate slips deeper beneath North America.

Earthquakes, the Buildup of Stress, and Deformation of the Earth

Imagine pushing a refrigerator or other heavy object across a carpeted floor—at first it will be stuck in place, but if enough force is applied, the friction can be overcome, and the object will suddenly lurch forward before it stops again. If there is a stiff spring between you and the fridge, as you push forward, the spring compresses, storing elastic energy in it. Eventually the force of the spring added to your pushing will overcome friction, and the fridge will

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slide forward. As the Pacific plate tries to push beneath North America, it compresses both itself and the North American plate, until the elastic energy stored in the crust by this compression is released in a sudden slippage on the fault.

Using ultra-precise Global Positioning System (GPS) surveying instruments *(Photos 1 and 2)*, we can measure the small motions of the earth's crust. The GPS receivers are small, easily portable, and require little power, all important factors for research in remote places like Aialik Bay. Portable GPS receivers are set up for a couple of days over a survey marker set into the ground, recording data from the GPS satellites. We use that data to determine the position of the survey marker, which is precise to several millimeters in three dimensions. An added benefit to this type of research is the low impact: researchers can obtain useful data without leaving a trace on the land (except for inconspicuous survey markers).

By repeating such surveys over a few years, we can measure the horizontal motion of the survey points, to a precision of about one-tenth of an inch (1-2 mm) per year. For example, the entire city of Seward is moving steadily to the north-northwest at a rate of 1.5 inches (35 mm) per year relative to the North American plate *(Figure 2)*. It will continue moving northward until the next big earthquake, when it will suddenly spring southward again as it did in 1964.

The fortieth anniversary of this incredible event is now upon us, so it is consigned to the distant past for most people. But several mysteries about the earthquake and its effects linger, and they are the subject of ongoing research. One especially intriguing feature of the earthquake is that the amount of slip on the fault was highly variable. Beneath Prince William Sound and the eastern Kenai Peninsula, the Pacific plate slipped an average of 60-100 feet (20-30 m) beneath North America. Beneath Kodiak Island, the Pacific plate slipped an average of 30-50 feet (10-15 m) beneath North America. But in between these two areas of high slip, the amount of slip was much lower, perhaps as little as 15 feet (5 m) or less. Why such a dramatic variation, and what does it mean for earthquake processes in general? Is this dramatic change reflected somehow in the present tectonic loading that is building up to the next earthquake?

Stuck or Not Stuck

It has been known for a long time that some subduction zones (places like southern Alaska where one plate thrusts beneath another) generate many, very large earthquakes, while others rarely generate any. One factor that affects the number and size of large earthquakes is the rate of plate motion. In general, a fast-moving plate will generate either more earthquakes or bigger ones as it subducts, compared to a slow-moving plate. This happens because over time the faster moving plate has to slip a greater distance. But the worldwide differences in rates of plate motion are not nearly large enough to explain the global variation in earthquake occurrence at subduction zones. There must also be variations in the amount of the plate interface that is stuck by friction.

The subduction zones that almost never have significant earthquakes seem to have a plate interface that slips slowly but steadily all the time, rather than being stuck most of the time and slipping only in earthquakes. These faults are somehow more slippery than usual, and they behave differently. The famous San Andreas Fault in California has a long section that shows this same kind of creep, and as far as we know never generates large earthquakes.

In regard to the low slip zone in the 1964 earthquake, questions remain. It could represent a "creeping section" that is unable to slip much in an earthquake because it constantly relieves stress by steady creep.

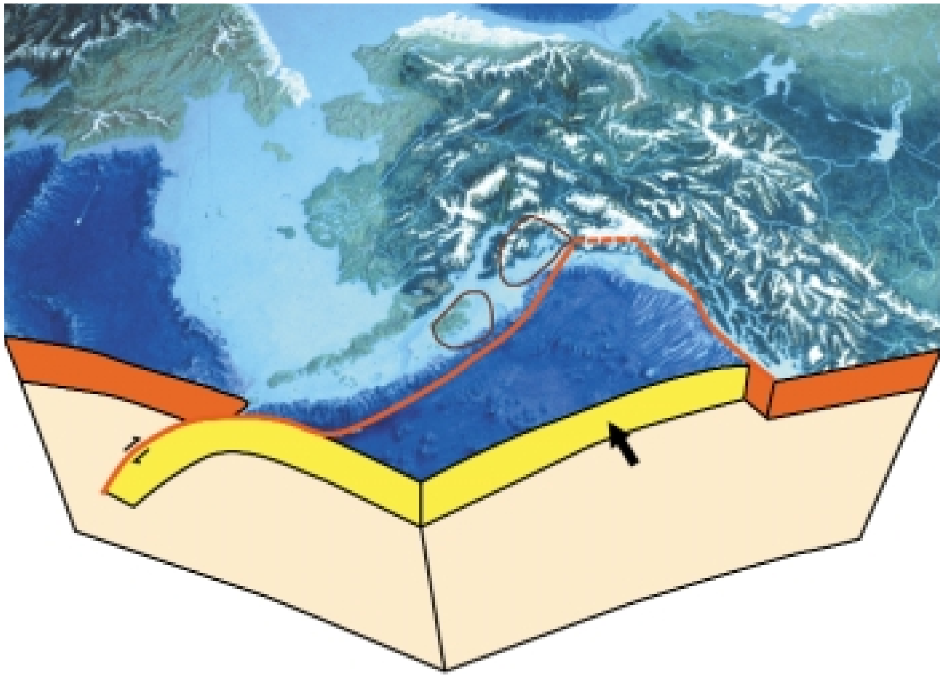

Figure 1. Cutaway view of the Pacific plate subducting, or thrusting beneath North America. The Pacific plate moves north-northwest at a rate of about 2.2 inches (about 5.6 cm) per year. The red lines mark the boundaries between the Pacific and North American plates. The two dark lines outline the regions of high slip in the 1964 Alaska earthquake.

Photograph ©Sigrún Hreinsdóttir

Photo 2. Researchers and equipment, which are small and easily portable.

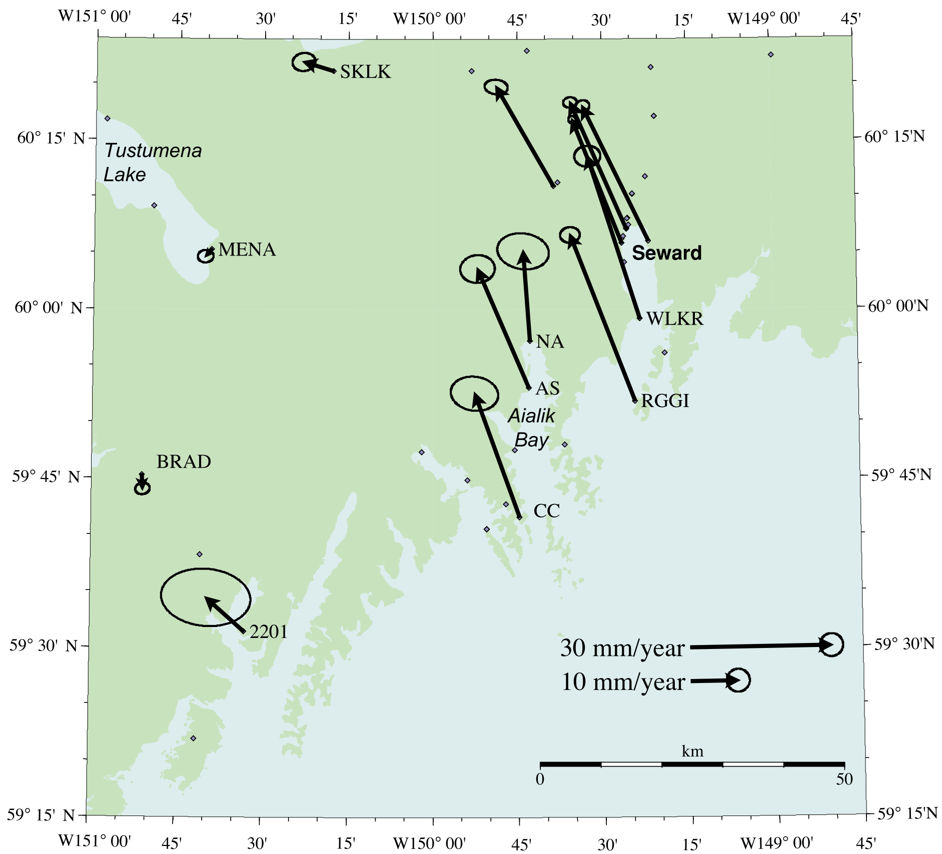

Figure 2. Velocities of sites in and around Kenai Fjords National Park, relative to North America. The northwestward motion results from the increasing compression of the North American plate. Comparing sites at similar distances from the coast reveals a substantial change across this region. For example, the site CC moves more slowly than RGGI, and the site 2201 more slowly than site AS or any of the sites in Seward.

Or, it may be no different from the regions to either side. In the latter case, the lack of slip in 1964 could be explained if there had been an earthquake in that section a century or two ago, relieving most of the stress there. The historical record in Alaska is short, so it is difficult to rule this out. Answering why there was a low slip zone is important not only for understanding how faults behave, but also for evaluating the earthquake hazards faced by cities like Homer, Seward, and Kodiak.

Fortunately, we can tell the difference between these two cases using motions derived from GPS data. In the first scenario, with the creeping fault, we expect to see little to no contraction in North America, because stress is neither building up nor compressing the western Kenai Peninsula. In the second case, we would expect to see significant contraction, the same as in Prince William Sound. The GPS data clearly point to the first explanation *(Figure 2)*. The contraction we would see from a locked fault is either much slower than we observe in Prince William Sound, or not there at all. This leads us to infer that most of or all of the plate interface beneath the western Kenai Peninsula is creeping steadily, and it will not slip much in future great earthquakes.

Although we are confident that the low slip zone is a “creeping section”, the exact length and width of the zone is unknown. There may be patches within the zone that are locked. The eastern boundary is also unclear. We know from prior work that the edge of the large slip zone lies near Seward, probably a bit to the west. In short, this boundary lies right beneath Kenai Fjords National Park.

In 2001 we began making measurements at several sites along the Pacific coast of the Kenai Peninsula, including sites within the park. In June 2002, UAF graduate student Sigrún Hreinsdóttir and Lissy Hennig, a summer intern from the Technical University of Dresden, Germany, surveyed sites in Aialik Bay with the assistance of Park Rangers Janette Chiron and Brandon Hallock. Despite generally bad weather and a huge storm that blew one instrument partially into the ocean (fortunately it was repairable), they successfully repeated surveys done in 2000 by a National Ocean and Atmospheric Administration team that was making an updated bathymetric map of the region.

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Most of our sites in the park have been surveyed at least twice, and they document a significant westward reduction in the amount of contraction of the North American plate *(Figure 2)*.

Our work continues, and we aim to answer the questions raised about the boundaries of the low slip zone and if there are locked segments within it. We are working to identify the location of the edge of the large locked patch and to make an estimate of the distance over which the interface changes behavior from fully locked to fully creeping. This is the first step in understanding what causes this change in behavior of the fault. A greater understanding of earthquakes, and an improved ability to forecast (or possibly someday predict) them, may be impossible until we have a better understanding of the physical properties and mechanics of fault behavior. Studies like this are steps toward that eventual goal, as we hope to learn what happens deep within the earth as tectonic forces build slowly toward the next great earthquake in southcentral Alaska.